INSTALLATION OF THE MINA, NEVADA, SEISMIC AND ACOUSTIC ARRAYS

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Sponsored by U. S. Department of Defense
Defense Threat Reduction Agency
Grant No.: DSWA01-97-I-0024

ABSTRACT

The Mina, Nevada, seismic array (NVAR) was installed in the Garfield Hills of west central Nevada, in December 1998, by the Southern Methodist University (SMU) Geophysics Laboratory. The array is a primary seismic station of the International Monitoring System (IMS) at 38.4°N and 118.2°W, as described in Annex I of the Protocol to the Comprehensive Nuclear-Test-Ban Treaty. The central site (NV01) of NVAR is located at 38.43°N and 118.3°W and is 11.3 km from the treaty coordinates. IMS Certification of the array is scheduled for August 1999. A complementary four-element acoustic array was collocated with sites NV01-04 in February 1999.

The short-period seismic array has an aperture of 4 km and consists of ten short-period Geotech GS-13 velocity sensors. Each element is powered by three 64-watt solar panels charging a 12-volt, 220-amp hour battery. The analog data are digitized at 40 samples/sec and authenticated using the AIMs and AIMAs that are part of the AQUINAS™ system designed and integrated by Science Horizons, Inc. Each site has intrusion alarms that alert both the authenticator and digitizer when the wellhead terminal or vault door is opened. Intra-array communication is accomplished by 900-MHz spread-spectrum radios and includes two repeaters atop mountain ranges between the SP array and the central recording facility (CRF) at Mina, NV. The array is polled from the CRF and the data are transmitted to Southern Methodist University by VSAT for processing and archiving. Alpha data are transmitted by land-line to the U.S. National Data Center.

The IMS-required broadband site for the array is collocated with station MNV in the Black Butte Mine northwest of Mina, Nevada, and consists of a three-component long-period (LP) sensor (Guralp CMG-3T) and three Geotech GS-13 short-period (SP) sensors. The combination of the LP and SP sensors meets the IMS requirements for a three-component broadband station for the Black Butte Mine. The array also consists of two LP sites (Geotech KS-54000s) that along with the BB site make up a tripartite array surrounding the SP sites.

Research efforts using data from NVAR are concentrated in three areas. The first is the identification of all events on or near the Nevada Test Site using array beam-forming techniques. The events are analyzed and cataloged and will soon be published on a web page. The second area of research is the creation of a ground truth database for Nevada and the surrounding states using seismic and acoustic data in an attempt to identify sources of man-made seismic and acoustic signals. Also underway, is the back-azimuth and phase velocity calibration of the array using regional and teleseismic earthquakes and explosions.

Key Words: seismic arrays, seismo-acoustic, data communications

OBJECTIVES

Annex I to the protocol of the Comprehensive Nuclear Test Ban Treaty (CTBT) calls for the construction of a primary seismic array near 38.4°N and 118.2°W. The Defense Threat Reduction Agency contracted the Southern Methodist University Geophysics Lab to install the array. SMU objectives were to: 1) Plan, design, and install the seismic array, integrate a four element infrasound array at the site, and prepare the seismic array for certification as an International Monitoring System primary seismic array; 2) Operate and maintain the array; 3) Calibrate the arrays; and 4) Construct regional ground truth databases using seismic and acoustic synergy.

RESEARCH AND DEVELOPMENT ACCOMPLISHED

Installation of Mina, NV Array

The Mina, Nevada, seismic array (NVAR) was installed in the Garfield Hills of west central Nevada, in December 1998, by the Southern Methodist University (SMU) Geophysics Laboratory. Table I shows the timeline for the installation of the array.

Event	Date
Noise Survey (Figure 1)	August 1997
Site Survey (Figure 2)	April 1998
BLM Application/Acceptance	May 1998/October 1998
Factory Acceptance of Data Acquisition Equipment (Figure 3)	November 1998
Borehole Drilling	November 1998
Central Recording Facility Civil Works (Figure 4)	November 1998
SP Array Installation (Figure 5) and NV32	December 1998
BB Installation at NV31/NV11 (Figure 6)	February 1999
Infrasound Sensor Installation	February 1999
Weather Station Installation	June 1999
Differential GPS Survey (Table II)	June 1999
NV33 Installation	Planned for August 1999
Mock Certification	Planned for August 1999
IMS Certification	Planned for Fall 1999

Table I. Timeline showing major events in the installation of the NVAR array.

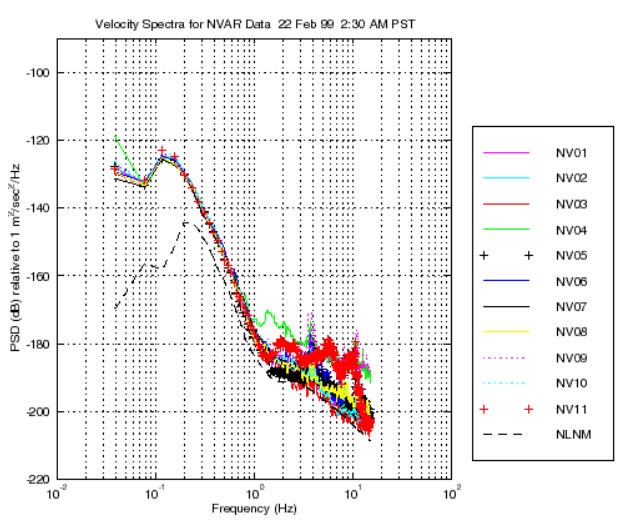

Figure 1. Velocity spectra for noise at NVAR. The spectra show data collected after the installation of the array that were calculated using a 1024 point Welch block averaging method with a Bartlett window

using 10 blocks with 50% overlap. The data are plotted in dB relative to the appropriate units, and for comparison, Peterson's (1993) New Low Noise Model is shown as the dashed line.

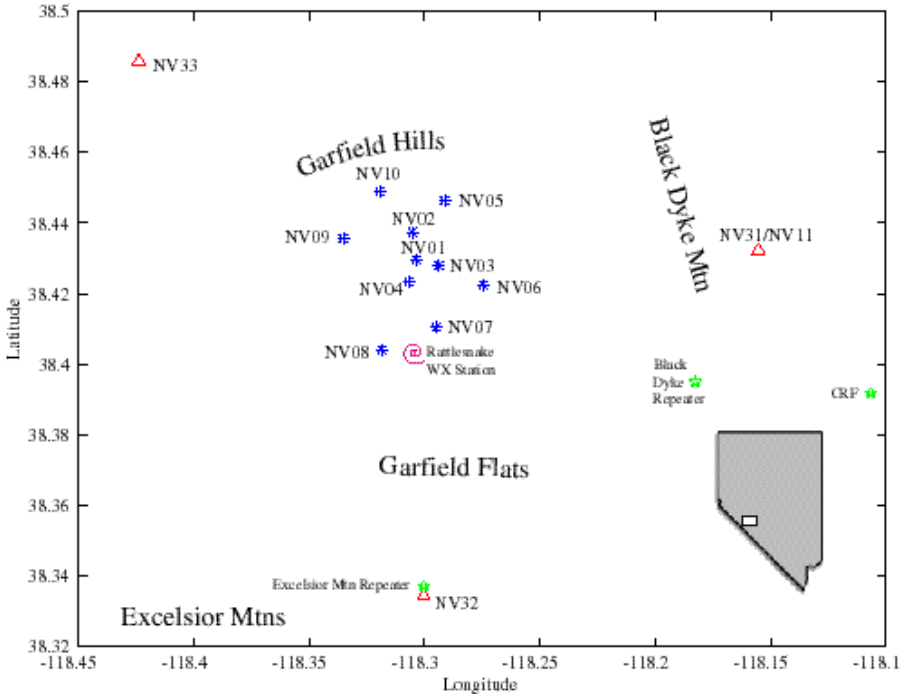

Figure 2. Map showing the elements of the NVAR array. Sites NV01-NV10 make up a 4 km aperture short-period array collocated with an infrasound array at sites NV01-NV04. Sites NV11, NV31, NV32, and NV33 comprise a broadband tripartite array. Also shown are the communication relay points, weather station, and Central Recording Facility (CRF).

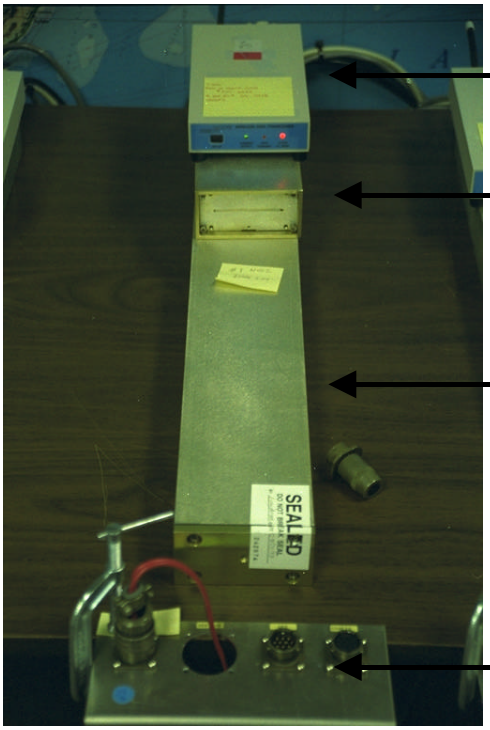

Figure 3. Field components for the AQUINAS™ System from Science Horizon, Inc., including cable connector, digitizer (AIM), data authentication unit (AIMA), and Freewave 900 MHz Spread Spectrum Radio.

Figure 4. The Mina, NV Municipal Building serves as the Central Recording Facility for NVAR. Data from the remote sites are polled by a CIM II (Science Horizons, Inc) using 900 MHz spread spectrum radios. Alpha data is then sent via land-line to the United States National Data Center and data is also sent to SMU for monitoring purposes via VSAT.

Figure 5. SP Array element. Each element is powered by three 64-watt solar panels charging a 12-volt, 220-amp hour battery. The analog data are digitized at 40 samples/sec and authenticated using the AIMs and AIMAs that are part of the AQUINAS™ system designed and integrated by Science Horizons, Inc. Each site has intrusion alarms that alert both the authenticator and digitizer when the wellhead terminal or vault door is opened. Intra-array communication is accomplished by 900-MHz spread-spectrum radios and includes two repeaters atop mountain ranges between the SP array and the central recording facility (CRF) at Mina, NV.

Figure 6. BB Array Element. The IMS-required broad band site for the array is collocated with station MNV in the Black Butte Mine northwest of Mina, Nevada, and consists of a three-component long-period (LP) sensor (Guralp CMG-3T) and three Geotech GS-13 short-period (SP) sensors. The combination of the LP and SP sensors meets the IMS requirements for a three-component broad band station for the Black Butte Mine.

Site	Site Info	Longitude (W)	Latitude (N)	Elevation (m)
NV01	sz, IS	118.303547	38.429609	2029.4
NV02	sz, IS	118.304863	38.437356	2094.3
NV03	sz, IS	118.293709	38.427909	1978.5
NV04	sz, IS	118.306792	38.423245	1983.5
NV05	sz	118.291255	38.446372	2186.6
NV06	sz	118.274397	38.422413	1935.5
NV07	sz	118.294853	38.410503	1849.0
NV08	sz	118.318444	38.404099	1798.2
NV09	sz	118.335177	38.435455	1918.1
NV10	sz	118.319363	38.448782	2132.6
NV11/NV31	sz,se,sn,bz,be,bn	118.155349	38.432049	1509.0
NV32	bz,be,bn	118.300299	38.334192	1783.8
NV33	bz,be,bn	118.423774	38.485762	1939.8

Table II. Locations for the elements of the NVAR array obtained by a differential GPS survey. The elevation listed is the elevation of the seismometer in the borehole or vault.

Calibration Studies

Currently, several studies are underway to calibrate NVAR for travel times, phase velocity, and back-azimuth. However, station corrections are needed due to large elevation differences before calibration studies can be completed. The elevation difference of the vertical elements at NVAR is up to 0.4 km for some elements of the array. Delays caused by elevation difference can be as large as 4 sample points (0.1 s) for a phase velocity of 4 km/s (at a sample rate of 40 samples/sec) therefore an elevation correction is necessary. The elements of the array are also located on different lithologies.

We analyzed 57 arrivals with steep incidence angles (core phases: PcP, PKP, PKKP, Pdiff) coming up to the NVAR array from events located by Prototype International Data Center between March and July 1999. The events had magnitudes $m_b \geq 4.0$ and were recorded at more than 10 stations.

Correction for elevation difference is made by subtracting the time required for waves to travel the vertical distance between the reference station (NV08 - lowest elevation) and each one of the other stations from the total time residual at each station. In order to obtain the matrix of raw time delays between the waveforms we applied the Cross-Correlation Method (Tibuleac and Herrin, 1997) for all the vertical channels but NV11. We used the calculated azimuth and the theoretical slowness to find the time correction for horizontal propagation of the waveforms across the array. We added this time correction to the raw time residuals and obtained the median of time residuals due only to elevation for each station. The resulting time residuals function of the elevation relative to NV08 are presented in Figure 7. The stations NV09 and NV05 are unusually fast compared to NV08. After ruling out a possible misalignment of the clocks, the reason could be variations in geology beneath the stations. Also, NV09 has a higher noise level than any other station.

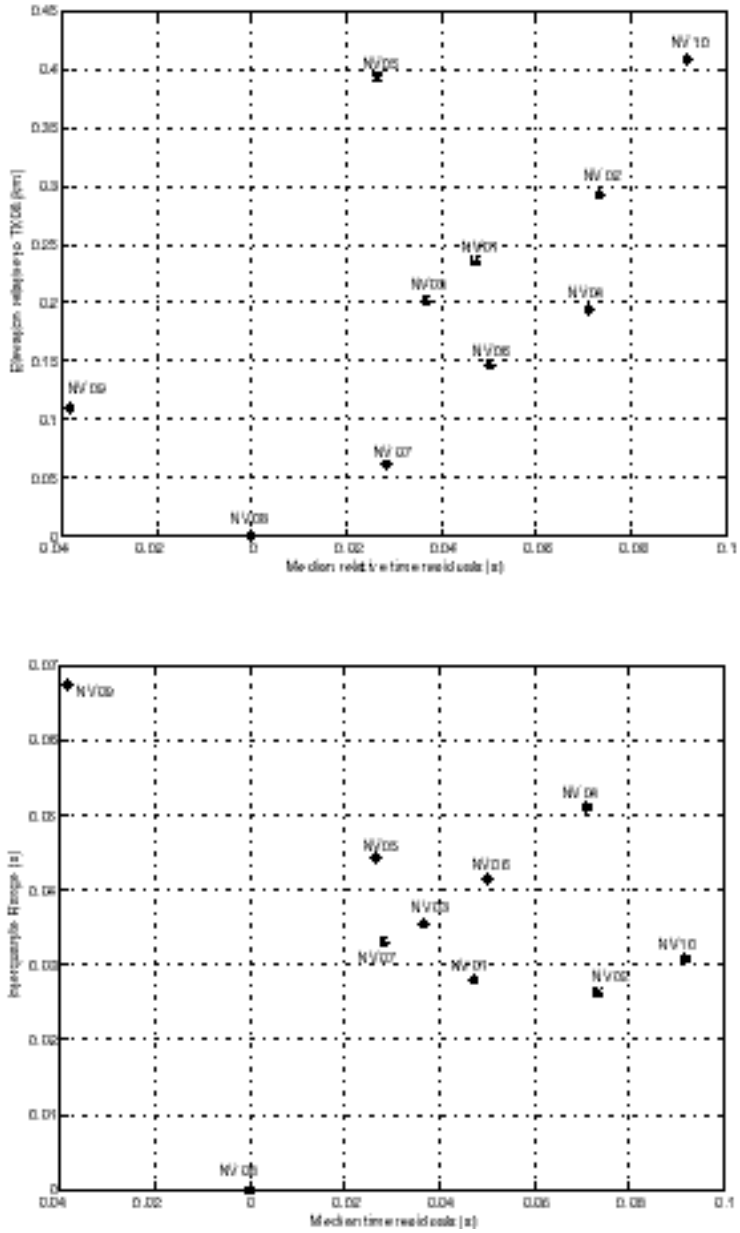

Figure 7. (Top) Elevation as a function of time corrections relative to NV08. (Bottom) Interquartile range as a measure of data dispersion (spread) as a function of time residuals.

As a measure of the data dispersion (spread) we chose the interquartile range (Figure 7). Because a stable replacement velocity cannot be calculated for all stations because of derivatives from a straight line relation between elevation and median correction (e.g. NV09, NV05), time corrections for each station will be used instead, as presented in Table III. The time correction for NV08 is zero seconds as it is the reference station.

Station	**NV01**	**NV02**	**NV03**	**NV04**	**NV05**	**NV06**	**NV07**	**NV09**	**NV10**
Time corr. (sec)	0.047	0.073	0.038	0.072	0.027	0.050	0.028	-0.038	0.092
Interquartile range (sec)	0.028	0.026	0.035	0.051	0.044	0.041	0.033	0.067	0.031

Table III. Time corrections and interquartile range for vertical elements at NVAR relative to NV08

NVAR Ground Truth Data Base Development

Two projects are currently underway using NVAR data for ground truth database development. The first is the complete analysis of seismic events on or near the Nevada Test Site. The analysis of these events can be found on *http://www.geology.smu.edu/~nts_events*.

The second project underway at the SMU Geophysics Laboratory involves the creation of a regional ground truth database. This database will be representative of the seismic activity caused by mine blasts located at regional distances from NVAR. The objective of the project is to create a database that will provide the information necessary to calibrate regional S-P and Lg-P time differences for NVAR and to evaluate the capabilities of the seismo-acoustic method to identify mine blast sources. At its completion, the database will contain definitive information about several hundred mine blast events from known sources located at regional distances from NVAR. A preliminary study has been undertaken to bench mark the data processing level of effort and resources required for the completion of the database. The seismological results of the benchmarking investigation are briefly summarized in the following paragraphs.

The NVAR seismic records were scanned continuously for a one month interval beginning 01 APR 99 to time the arrivals and measure the amplitudes of the phases of events that satisfied the following constraints:

- The event must occur during local daylight hours, Monday through Saturday, inclusively;
- The P signal to noise ratio must be greater than 2:1;
- The horizontal phase velocity of the P phase must be less than 10 km/s.

During the month of April 1999, 299 events were found to satisfy these constraints. This data set was then examined to identify possible mine blast events. It was shown that the association of an infrasound signal with a seismic event uniquely identifies the source of both as a vented explosion (Sorrells *et al.,* 1997). If, in addition, a population of vented explosive sources cluster in both time and space then it may be safely inferred that they are the products of active mining operations. Consequently, NVAR records were scanned for infrasound signals that could be associated with seismic events in the bench mark population. This search resulted in the identification of a subset containing 16 vented explosive sources. The epicentral distribution of the events in the subset is shown in Figure 8. The absence of obvious spatial clustering is attributed to the small size of the subset and the wide azimuthal dispersion of the vented explosive sources. As seen in Figure 9, this subset is characterized by significant temporal clustering. The histogram seen in this figure illustrates the frequency of occurrence distribution for the origin times of the events in the subset as referenced to local daylight savings time. Notice that the distribution is skewed and possibly bimodal. The activity increases dramatically after about 1300 hours and again after 1700 hours local time. These times typically coincide with the end of the lunch break and the end of the work-day for most commercial enterprises. This type of temporal clustering is a common characteristic of the seismic activity associated with active mining operations. Consequently, the members of the vented explosion subset are tentatively identified as mine blasts.

The frequency of occurrence distribution for the origin times of all the events in the bench mark population is seen in Figure 10. Notice that it resembles the distribution seen in Figure 9. From this resemblance, it is inferred that mine blasts account for a fairly significant fraction of the seismic events in the bench mark population. Further evidence supporting this inference is found in Figure 11. The data shown in this figure are the epicenters of the events occurring in the 1300-1500 hour and 1600-1800 hour local time periods. Notice that during these two high activity time periods, spatial clustering is seen in one area northeast of NVAR (presumed to be the gold mines of the Battle Mountain complex).

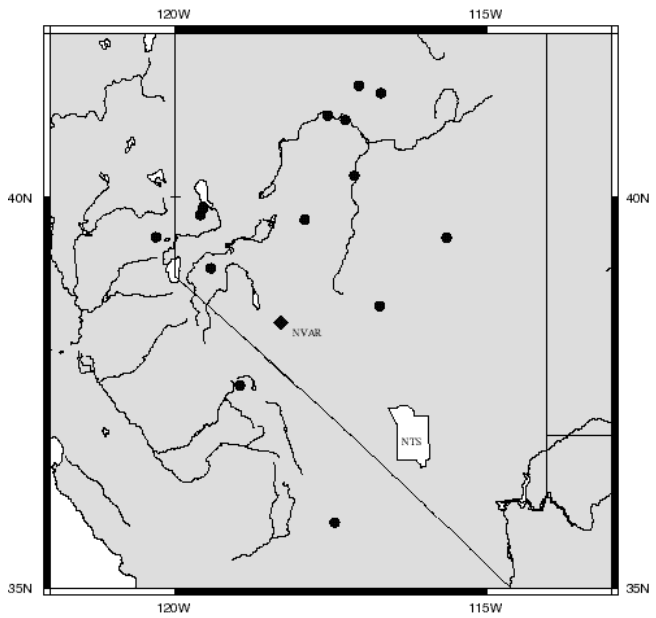

Figure 8. Locations of events for which seismic and acoustic signals were associated.

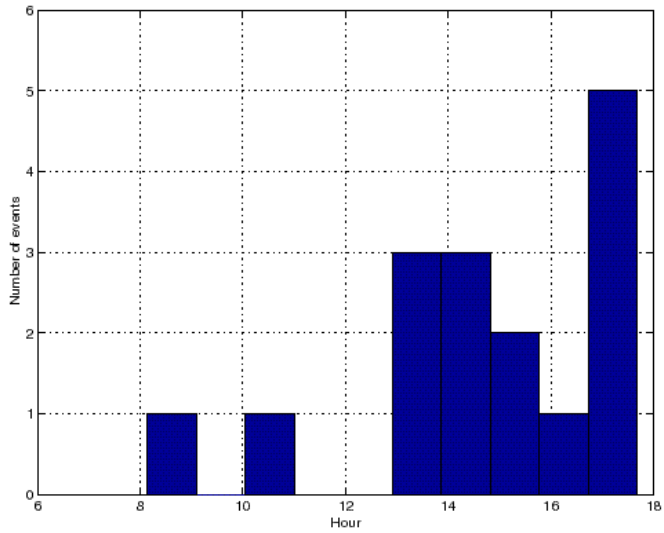

Figure 9. Local origin times of seismo-acoustic events recorded at NVAR for April 1999.

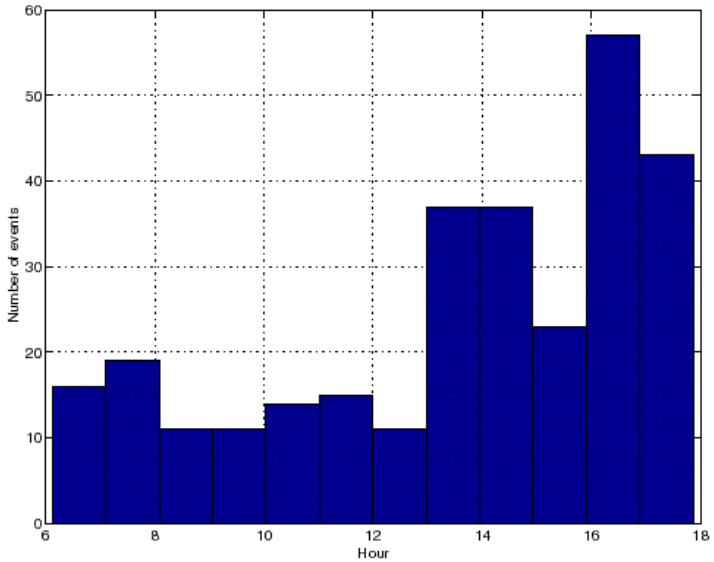

Figure 10. Occurrence of all events recorded at NVAR in April 1999.

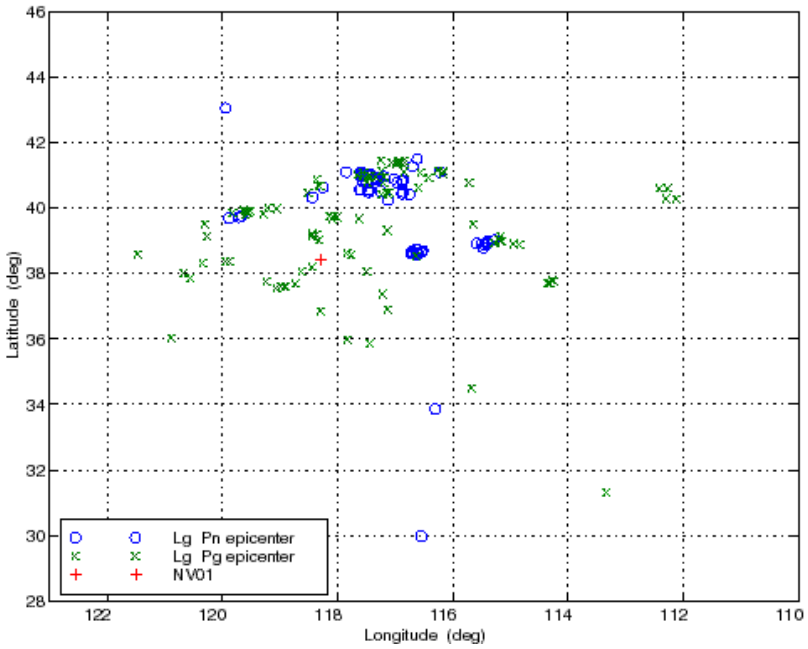

Figure 11. Epicenters for events located at NVAR occurring in the 1300-1500 hour and 1600-1800 hour local time periods.

CONCLUSIONS AND RECOMMENDATIONS

SMU Geophysics Laboratory installed the NVAR seismic array near Mina, NV and began operations in December 1998. The array fulfils a United States obligation for the Comprehensive Nuclear Test Ban treaty and consists of 10 short-period seismometers (Geotech GS-13s) with an aperture of 4km. The inner ring of array elements is collocated with a four element infrasound array. The broadband site for the array is located in the Black Butte Mine northwest of Mina, NV and consists of three GS-13s (Z,N,E) along with a Guralp CMG3-T. This station is also a site in a broadband tripartite that surrounds the short-period array.

Authenticated data from the borehole or vault is transmitted to a Central Recording Facility (CRF) using spread spectrum radios. From the CRF, the data is forwarded via land-line to the USNDC and to the SMU Operations and Maintenance center where the data is monitored for quality assurance, archived, and processed. Calibration and ground-truth data base development is currently underway using NVAR seismic and acoustic data. We hope to fully certify NVAR as an IMS array in the Fall of 1999.

ACKNOWLEDGMENTS

The authors wish to thank Scot and Cheryl Chamberlain for continued support at NVAR. We also appreciate the support offered by the engineers at Science Horizons both during and after the installation. We also wish to thank Don Rock and Marv Denny (Lawrence Livermore National Labs) for their support in installing the BB station at the Black Butte Mine and Randy Rembold and Dick Kromer (Sandia National Labs) for their help during the certification process.

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